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DESIGN OF LOWER LIMB EXOSKELETON ROBOT

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DESIGN OF LOWER LIMB EXOSKELETON ROBOT

TAN CHEE JUN

A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Mechatronics Engineering with Honours

Faculty of Electrical Engineering

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“I declare that this report entitle “Design of Lower Limb Exoskeleton Robot” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.”

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ABSTRACT

Every year, many workers suffer from work-related musculoskeletal disorders (MSD) cases that are caused by long term walking and standing. This problem can be overcome by using exoskeleton which is a type of wearable robots that can augment the performance of an able-bodied user. A lower limb exoskeleton can be used to improve muscle endurance of the user by providing support torque to the limbs. There are many studies that use hydraulic actuator to actuate the lower limb exoskeleton which have several drawbacks like dirty, noisy and high power consumption. Therefore, electrical actuators that are clean, silent and less power consuming are used in designing the lower limb exoskeleton in this project. Hence, to design an electrical actuated exoskeleton, this project is aimed to derive the mathematical model and joint torque equations, to design a lower limb exoskeleton using electrical motors from the market and to validate the design of the lower limb exoskeleton by simulation. In order to achieve the objectives, mathematical model of the exoskeleton are derived using kinematic analysis and the required joint torque are derived using force analysis. Besides that, motors and gearboxes are selected and incorporated into the design of the exoskeleton. After that, finite element analysis (FEA) and motion analysis test on the design model of the exoskeleton are conducted using SolidWorks. The FEA test shows that the structural strengths of all the exoskeleton links are able to support the user under maximum torque condition. Besides that, the motion analysis done also shows that the actuator units selected are able to support a 100kg user and the exoskeleton to walk. However, there are limitations for the actuator units selected which requires further testing and improvement. In conclusion, all the objectives are achieved but the exoskeleton still requires further studies and improvements.

ABSTRAK

Setiap tahun, ramai pekerja mengalami malasah gangguan muskuloskeletal disorder(MSD) yang disebabkan oleh berdiri dan berjalan untuk jangka masa panjang. Masalah ini boleh diatasi dengan menggunakan Exoskeleton yang merupakan jenis robot boleh pakai yang boleh meningkatkan prestasi seorang pengguna yang berbadan sihat. Exoskeleton untuk kaki boleh digunakan untuk meningkatkan daya tahan otot pengguna dengan menyediakan sokongan tork kepada anggota badan. Terdapat banyak kajian yang menggunakan penggerak hidraulik untuk menggerakkan Exoskeleton mempunyai beberapa kelemahan seperti kotor, bising dan penggunaan tenaga yang tinggi. Oleh itu, penggerak elektrik yang bersih, senyap dan kurang memakan kuasa digunakan dalam mereka bentuk Exoskeleton dalam projek ini. Oleh itu, untuk mereka bentuk sebuah kulit luar digerakkan elektrik, projek ini bertujuan untuk memperolehi model matematik dan persamaan tork bersama, untuk mereka bentuk Exoskeleton menggunakan motor elektrik dari pasaran dan untuk mengesahkan reka bentuk Exoskeleton dengan simulasi. Dalam usaha untuk mencapai objektif, model matematik Exoskeleton telah diperolehi dengan menggunakan analisis kinematik dan tork bersama yang diperlukan telah diperolehi dengan menggunakan analisis kuasa. Selain itu, motor dan kotak gear telah dipilih dan dimasukkan ke dalam reka bentuk Exoskeleton. Selepas itu, Finite Element Analysis (FEA) dan analisis pergerakan kepada model Exoskeleton telah dijalankan menggunakan SolidWorks. Ujian FEA menunjukkan bahawa kekuatan struktur semua anggota Exoskeleton dapat menyokong pengguna di bawah keadaan tork maksimum. Selain itu, analisis pergerakan yang dilakukan juga menunjukkan bahawa unit penggerak dipilih mampu menyokong pengguna 100kg dan Exoskeleton untuk berjalan. Walau bagaimanapun, terdapat batasan bagi unit penggerak terpilih yang memerlukan ujian lanjut dan penambahbaikan. Kesimpulannya, semua objektif tercapai tetapi Exoskeleton ini masih memerlukan kajian lanjut dan penambahbaikan.

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LIST OF ABBREVIATIONS

MSD	-	Musculoskeletal Disorder
LLD	-	Lower Limb Musculoskeletal Disorder And Injuries
DC	-	Direct Current
EMG	-	Electromyography
DH	-	Denavit-Hartenberg
m	-	Mass
l	-	Length
T	-	Torque
FEA	-	Finite Element Analysis
s	-	Step Length
H	-	Maximum Lift Height

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Musculoskeletal disorders (MSD) are a form of injury or discomfort that normally involves our body parts below the skull including joints, muscles and so on. This form of injuries normally befalls on our limbs, neck and back. MSD commonly arises from acute trauma which happens when the body supporting structure is subjected to a large single load that exceeds the body's limitations for instance like heavy lifting and moving heavy stuffs. Besides that, MSD are also caused by the overuse trauma which happens when the body is subjected to repetitive movement while under loading condition for example like unloading goods from trucks.

In year 2005, out of 1012000 cases of work related MSD reported in the United Kingdom, there are 18%, which is about 185000 people that suffers from the lower limb musculoskeletal disorder and injuries (LLD). [1] LLD poses a great effect on the patients; it can affect the patient in level from causing discomfort to immobility and thus decreasing the quality of life. Besides that, LLD also affects the employer in terms of work time lost and decrease in production rate. This shows that LLD possesses a great threat to not only the society but also the industry and the consequences of it are critical.

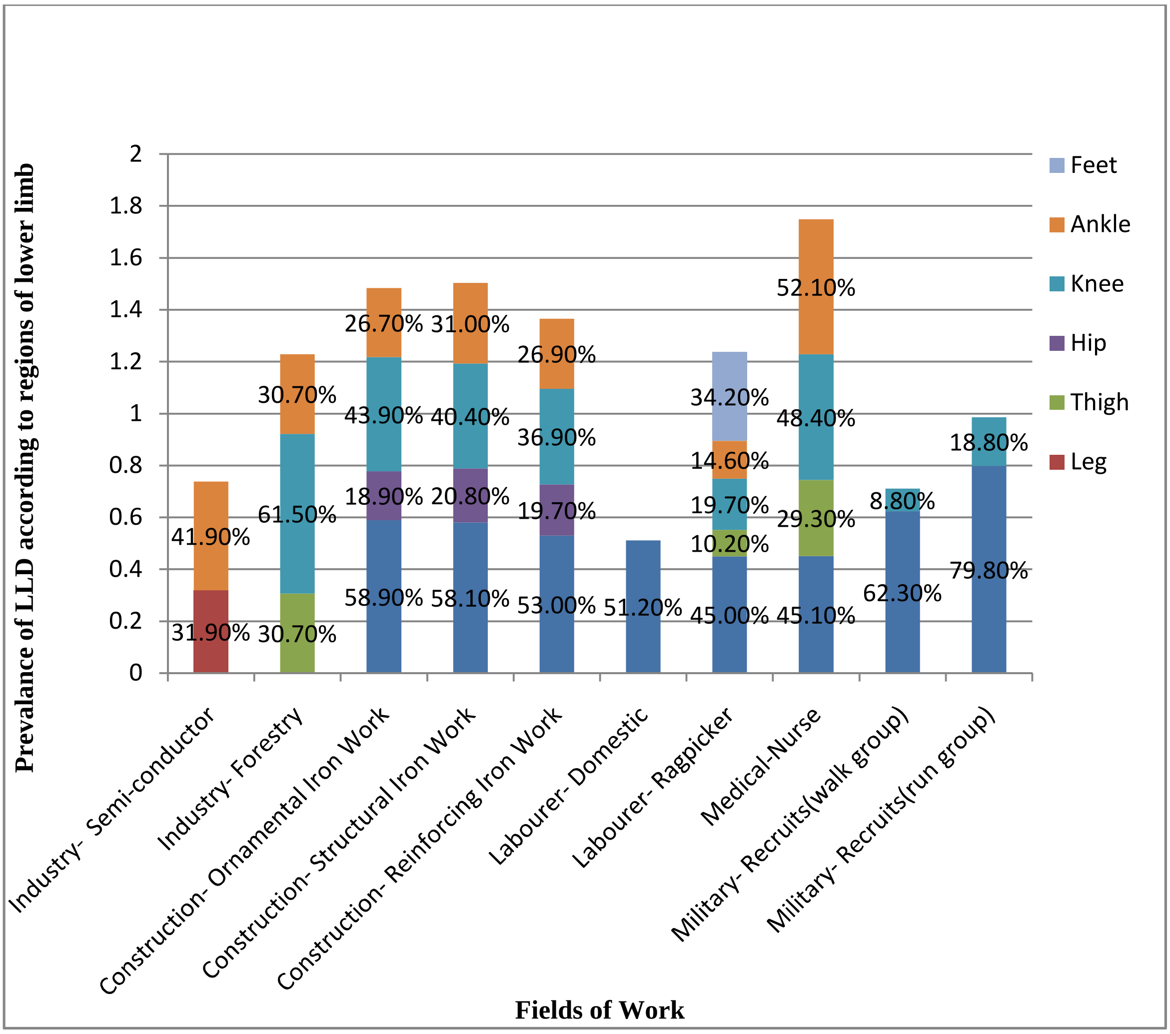

Figure 1.1: Prevalence of LLDs reported for different field of work. [2]

Figure 1.1 shows the prevalence of LLD reported in different field of work. The statistics shows that more than 50% of the LLD reported involve the injuries of the full lower limb in the field of construction field. This is probably due to the heavy lifting and long term standing that the work requires. Besides that, the medical field also shows a high prevalence of LLD which about half of the injuries reported involve ankle, knee and lower limb. This is caused by the long term walking and standing working as a nurse. Apart from that, the military field also shows the highest prevalence of LLD which is more than 60% in the form of full lower limb pain. This is no surprise as the soldiers need to carry heavy loads and walk or run for a long distance. For the industry worker however, only parts of the lower limb like ankle and knee shows a high prevalence of LLDs reported. [2]

This shows that how common are LLDs occurs in not only the industry but also some other fields of work. This project can help in reducing the occurrence of the LLDs by providing the support to the workers lower limb.

1.2 Problem Statement

With the widespread presence of lower limb musculoskeletal disorder and injuries, it is not an issue that can be ignored. Patients that suffer from lower limb musculoskeletal disorder and injuries (LLD) have reduced mobility due to conditions like osteoarthritis and bursitis. [2] These conditions that lower mobility will cause inconvenience in life for the patients as they cannot perform daily life activities as they used to be. This project of designing an electrical powered exoskeleton will help in preventing the development of LLDs in fields of work with high risk like construction and military. This will help to reduce the number of LLD cases in the society.

Some of the previous studies have incorporated hydraulic cylinders in their designs to actuate the exoskeleton. However, using hydraulic actuators to provide actuation have their downsides. One of it being the complexity of the system due to the reason it needs both hydraulic system for the actuation and electrical system for the sensors and control of the exoskeleton. Besides that, oil leakage can occur which will reduce the performance and soil the user. Moreover, hydraulic actuation’s power consumption is almost 2 times of that of electrical actuation. [4,5]

Although electrical powered exoskeleton can provide the ideal operation condition for the user, it has a problem that needs to be overcome. The problem being that it is difficult to find the suitable sized electrical motor in the market to provide actuation. For instance, the hip of a 75kg man requires a maximum of 80Nm of joint torque during a walking cycle. [3] It is possible to find a servomotor that can produce 80Nm but it is difficult to find a servomotor that produce that amount of torque that is small and light. [5]

However, a drive system can be incorporated to the design to produce sufficient amount of torque with smaller sized electrical motor. Hence, this project is purposed to provide a design of electrical powered exoskeleton with clean operation, less power consuming and less complex of the overall system.

1.3 Objectives

1. To derive mathematical model of lower limb using kinematic analysis and formulate joint torque.
2. To design an electrical powered lower limb exoskeleton using Solid Works.
3. To validate the design of exoskeleton in terms of structural strength as well as joint torque base on the motor available on the market.

1.4 Scope

The scope of this project is to design a lower limb exoskeleton actuated by electrical actuator. Since the average weight of adult Malaysian men is 61.8kg, the lower limb exoskeleton should be able to support user up to 100kg. [36] This project will focus on supporting a 100kg able-bodied user at ground level walking by lifting the limbs. The lower limb exoskeleton will be actuated by electrical actuator available on the market. In this project, the kinematics of lower limb exoskeleton will be derived. Besides that, the mechanical design of the lower limb exoskeleton will be discussed. Apart from that, the lower limb exoskeleton will be simulated to test the structural strength and torque requirement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Exoskeleton is a device that can augment the performance of an able-bodied wearer. It is used to augment the strength or the endurance of the wearer through various means. There are many types of exoskeleton which are mainly grouped into either full body exoskeleton or partial exoskeleton which further divides into upper limb exoskeleton and lower limb exoskeleton. As the name suggested, full body exoskeleton improves the performance of both the upper and lower limb of the user be it the strength or the endurance. For upper limb exoskeleton, the exoskeleton will augment the performance of user from the waist up including torso and arms. Whereas, the lower limb exoskeleton will improve the performance of the user's legs. This research will focus on the lower limb exoskeleton. [6]

The lower limb exoskeleton is further divided into two types which are series and parallel. Series lower limb exoskeletons are the ones that are applied in series with human legs to store energy and release far greater strain energy. [8] This type of exoskeleton works by storing energy when the user's feet are striking the ground and release it by pushing the user to lift. By doing this, it reduces the effort for the user to move and hence reduce the metabolic cost. The most common example of this type of exoskeleton is the elastic shoes.

The other type of exoskeleton is known as parallel exoskeleton which is applied in parallel with human lower limb to change the limitations of the human body. For this type of exoskeleton there are various designs that serve different purposes for the wearer. One of which is for load transfer. This design transfer load as well as the body weight directly to the ground which will reduce the metabolic cost of the wearer for loads carrying and ultimately enhance the endurance of the wearer. One of the examples for this type of exoskeleton is Berkeley Lower Limb Exoskeleton (BLEEX) developed by University of California, Berkeley. [3, 8] There is another design that is intended for torque and work augmentation. This sort of design augments joints torque and power of the user allowing them to lift heavy thing and perform daily activities with ease. Besides that, it also helps in reduce joint pain for user. However, this design normally does not transfer substantial load to the ground unlike the previous design mentioned. An example of this type of exoskeleton is the Hybrid Assistive Limb (HAL) developed by Cyberdyne [7, 8]. Besides that, there is another designed that aimed to increase the users muscle endurance. This type of exoskeleton utilizes the fact that only a small portion of our muscles are fatigue during an exhaustive exercise. It redistributes the work load over a greater number of muscles, particularly the muscles that are not easily fatigue. This design simply uses spring that will stretch by unused muscles to store energy and then release it to assist the muscles that are easily fatigue. Hence, the muscle endurance of the wearer can be increased using this design. [8]

Since there are so many designs for exoskeleton, a design suitable for an intended application should be determined and suitable components of the exoskeleton should be selected to make sure that the exoskeleton designed works as it should.

2.2 Biomechanics of Human

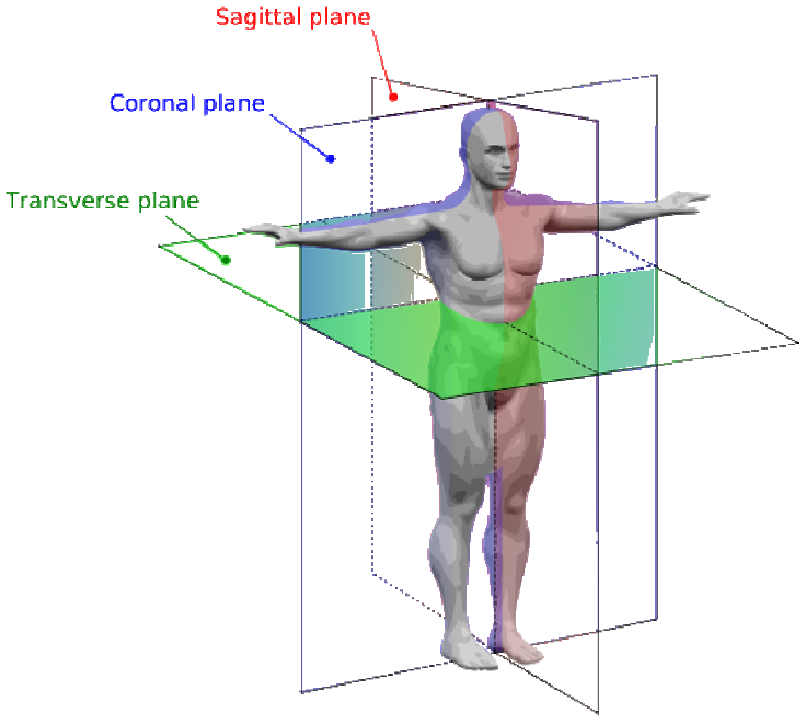

Figure 2.1: Reference plane of human body.[35]

Human's movement and motion are very complex due to the vast number of degree of freedom of our body. However, most of our daily life motions that require large torque and power are performed in the Sagittal plane. [34] These motions include walking, running, standing up and more. This is the reason why many of the previous studies focused on actuation of joint in Sagittal plane particularly in flexion/extension of hip, knee and ankle as seen in [30].

There are many degrees of freedom for human's lower limb. However, it would be a waste to actuate all of them as some of them do not require high power. According to [30], the flexion/extension of hip, knee and ankle requires the most power which needs to be actuated.

In conclusion, actuations should be provided to the flexion/extension of hip, knee and ankle whereas the other un-actuated joints are left to rotate freely to minimize the hindrance of the user's movements.

2.3 Actuators

Actuators are the device that provide motion for the exoskeleton and hence support the wearer's limb motion. It takes the command from the controller and provides motion according to the requirement at a certain instant. Electrical Actuator is one of the most popular choices due to its clean and silent operation as well as lower power consumption than others [5]. Some of the electrical actuators used by previous studies include DC Servomotor, Linear Actuator and Series Elastic Actuator.

DC Servomotor is a popular choice in providing actuation for robots as well as exoskeletons. It is essentially a motor with built-in position feedback. One of the reasons it is often used as an actuator is because of its simplicity and convenience to apply. [21] DC Servomotor can be easily controlled by controller which sends signal to it. Unlike any other actuator, the direction, speed and even position of the motor can be easily controlled by electronics. Moreover, DC servomotor provides precise positioning because of its built-in position feedback which gives an accurate control of its motion and position. . It provides clean and silent actuation of exoskeleton compared to the other which makes it suitable for application in any environment, indoor or outdoor. Apart from that, it is relatively compact compared to other electrical actuators is also one of the reason why it is such popular choice. [21] This is why it is normally positioned on the exoskeleton's joint that need to be actuated as seen in [18, 19, 21, 27]. However, there are some studies that position it away from the joint and transmit power through a drive system like chain or cable. [20, 23] Despite the compact size, a DC Servomotor with high torque and small size is not very easy to find. That is why Servomotors are normally coupled with suitable reducers to provide high torque and fast response motion in a small package. DC

Servomotors are chosen to be used by previous studies are also because of its high energy efficiency. [21]

There are studies that use linear actuator as their actuation system for their exoskeleton. [22, 23] Linear actuator consists of an electric motor and a leadscrew which translate the rotational motion provided by the motor into linear motion. It is chosen by studies in [22, 23] because of its high load capacity which means it can provide high force output. Apart from that, reasonable price is also one of the advantages of the linear actuators. However, there are some drawbacks of this type of actuator. One of it being that it is normally large and bulky because it needs to house the components like leadscrew, motor, gearing, bearing and other components. Besides that, the moving parts of the actuator are prone to wear and tear due to frictions. The linear actuator also has a limited range of motion as the leadscrew can only extend for a limited length only.

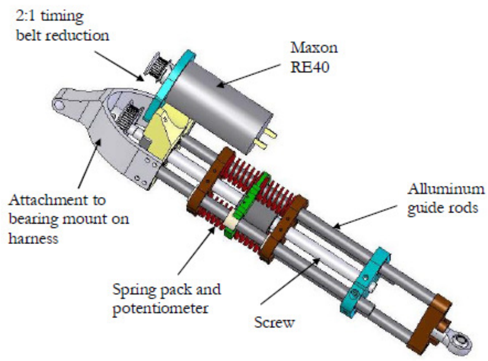

Figure 2.2: Linear series elastic actuator[25]

Linear Series Elastic Actuator is also a type of actuator used to provide motion for the exoskeleton. This actuator utilizes an electric motor coupled with lead ball screw and spring pack to provide linear motion as shown in Figure 2.2. It has a spring pack in series with the output of the motor. Some studies chose this type of actuator because it provides a better way to implement light and inexpensive force control. [25] Apart from that, it is said to be shock tolerant, low impedance and provides energy storage due to the spring pack incorporated in the design. [10] However, the size of Series Elastic Actuator is usually larger than other alternatives because it the components it needs. It is very hard to fit an